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Cellulose, its structure and properties.

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Cellulose, its structure and properties.

Properties of Cellulose

Cellulose is a complex carbohydrate, or polysaccharide consisting of 3,000 or more glucose units. The basic structural component of plant cell walls, cellulose comprises about 33 percent of all vegetable matter (90 percent of cotton and 50 percent of wood are cellulose) and is the most abundant of all naturally occurring organic compounds

A natural polymer made up from D-glucose ($C_6H_{12}O_6$) monomer units, cellulose contains glucose units which link together to form long unbranched chains.

Structure of Cellulose

As shown in figure 1 below, cellulose has a structure in which a -O-glycosidic bond linking the monomers is formed. This is done by eliminating a molecule of water from two β -D-glucose molecules in a condensation reaction. As can be seen in figure 1, the glycosidic bond joins carbon atom 1 on one glucose ring to carbon atom 4' on the adjacent ring; hence, cellulose can be described as poly(1,4'- β -D-glucose).

Figure 1.

The polymer chains in cellulose takes up a linear structure due to the 1,4- β glycosidic linkages. The repeating unit in cellulose is actually made up of two glucose units with each glucose unit in the linear chain being 'turned over' when compared with its preceding unit. Because of the positioning of the three hydroxyl groups on each glucose monomer, strong hydrogen bonds are formed between these and the hydroxyl groups on adjacent chains. The effect this has can be seen in figure 2 below.

Figure 2

Because of this rigid, almost tessellating structure between its chains, cellulose is:

- a rigid and fibrous polymer
- insoluble in water
- suitable for structural roles in plants

Cotton

Cotton is composed of 87-90% cellulose with the cotton fibres containing polymer chains in both amorphous and crystalline forms. The chains contained within the microfibril are held together by hydrogen bonds. Because cotton is constructed largely of cellulose, it is a material that is stiff and has a high tensile strength. Also, due to the large number of hydroxyl groups on the polymer chains, cotton absorbs water without actually feeling wet.

In general, it is because of the large percentage of cellulose that cotton is made of that cotton is such a versatile and widely used material.

Viscose Rayon

Viscose rayon can be produced in a variety of forms. Its ability to absorb moisture makes it ideal for viscose clothing. Often marketed and sold as artificial silk, it is widely used in outdoor clothes. It is also used in carpets and other home furnishings and for industrial applications such as tire cords and surgical materials.

The manufacture of viscose rayon is outlined below:

Figure 3

Cellophane

Cellophane can be obtained when the viscose solution obtained from the methods outlined above is extruded through a narrow slit (instead of through spinnerets) into an acid bath. The acid regenerates the cellulose, forming a film. Further treatment, such as washing and bleaching, yields cellophane. Highly impermeable to dry gases, grease, and bacteria, cellophane is used mainly to package food and other perishables. It is frequently given a moisture-proof coating and is sometimes dyed.

Cellulose Nitrate

The manufacture of cellulose nitrate is shown below:

Figure 4

Cellulose trinitrate is used as a propellant for bullets due to the fact that when most of the -OH groups are nitrated, it can be explosive. Celluloid, a plastic used previously to make cine films and X-ray films was made by treating cellulose with dilute nitric acid and mixing the product with camphor (to stabilise the celluloid nitrate). Celluloid was used for a variety of plastic items from spectacle frames to imitations

of animal parts such as ivory, and is still used in the manufacture of table-tennis balls and specialised laquers.

Cellulose Ethanoates

The process of manufacturing cellulose triethanoate is outlined below:
Figure 5

The ester that results from this dissolves in organic solvents, which in turn can be used to make plastics. Alternatively, a process called dry spinning is used; instead of being extruded into an acid bath, the filaments are extruded into the air, resulting in the volatile solvent evaporating from the polymer as it leaves the spinneret.

The cellulose triethanoate in which the polymer chains are no longer held together by hydrogen bonds, can be partially hydrolysed leaving an average of two ethanoate ester groups per glucose monomer. This polymer was marketed as Dical and contained -OH groups to prevent the build up of static electricity unlike its predecessor, Tricel. Cellulose ethanoate can be extruded through a narrow slit to give a plastic film similar to cellophane.

Tencel

Due to several favourable aspects, tencel is used to make clothes. When combined with other materials it offers a variety of uses such as bank notes, tea bags etc. Tencel does not require a derivative and is produced directly from solubilised cellulose. The production and breakdown of tencel is outlined below;

Figure 6

Stagnation of manufacture of cellulose-derived polymers

The reasons as to why the manufacture of cellulose-derived polymers had stagnated are as follows:

- Ø Economic factors - with regards to viscose rayon, for example, the cuprammonium now exists on a very small scale.
- Ø Weaknesses started to be recognised - again using the example of rayon, it was soon realised that despite the numerous advantages, the material became too clammy in hot or cold weather.
- Ø Hazards - celluloid, for example, when ignited burns furiously.
- Ø Environmental factors - the manufacturing processes involve the use of hazardous material, leading to air and water pollution.
- Ø Synthetic polymers was becoming more and more popular.

Renewed interest

The reasons as to why there is a renewed interest in cellulose fibres are as follows:

- Ø Over the last twenty years there has been a large investment on technology to reduce the amount of chemicals which cause pollution and to recover and reuse them.
- Ø Tencel, a revolutionary new material in the world of design, was developed.

- Ø Growing concerns over the use of fossil fuels, from which derived the majority of synthetic fibres.
- Ø Prior to the arrival of tencel, the manufacturing of most fibres derived from cellulose involved the making and unmaking of derivatives and generated relatively large amounts of noxious effluents.
- Ø Cellulose is a renewable resource, unlike oil or wood, which synthetic fibres depended on.
- Ø There was particular interest in lyocell due to the fact that it could be produced directly from solubilised cellulose. Its strength made it ideal for blending with other materials. Lyocell, as well as allowing faster processing, is strong enough to withstand modern dying and finishing processes. Lyocell, when wet, still retains 85% of its dry strength. Large investments continue to be made as prices fall steadily whilst demand continues to increase.

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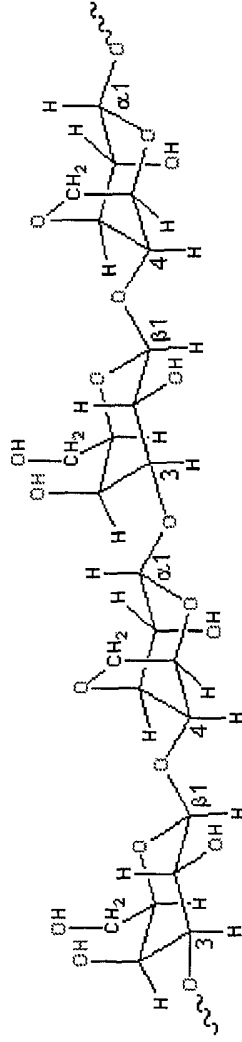


Agar

Source

Agar (E406) is prepared from the same family of red seaweeds (*Rhodophyceae*) as the carrageenans. It is commercially obtained from species of *Gelidium* and *Gracilaria*.

Structural unit



Agar consists of a mixture of agarose and agarpectin. Agarose is a linear polymer, of molecular weight about 120,000, based on the $(1 \rightarrow 3)$ - β -D-galactopyranose- $(1 \rightarrow 4)$ -3,6-anhydro- α -L-galactopyranose unit; the major differences from carrageenans being the presence of L-3,6-anhydro- α -galactopyranose rather than D-3,6-anhydro- α -galactopyranose units and the lack of sulfate groups. Agarpectin is a heterogeneous mixture of smaller molecules that occur in lesser amounts. Their structures are similar but slightly branched and sulfated, and they may have methyl and pyruvic acid ketal substituents. They gel poorly and may be simply removed from the excellent gelling agarose molecules by using their charge. The quality of agar is improved by alkaline treatment that converts of any L-galactose-6-sulfate to 3,6-anhydro-L-galactose.

Molecular structure

Agarose molecules have molecular weights about 120,000. The gel network of agarose contains double helices formed from left-handed threefold helices. These double helices are stabilized by the presence

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of water molecules bound inside the double helical cavity [508]. Exterior hydroxyl groups allow aggregation of up to 10,000 of these helices to form suprafibers.

Functionality

Agar is insoluble in cold water but dissolves to give random coils in boiling water. Gelation follows a phase separation process [501] and association on cooling ($\sim 35^{\circ}\text{C}$), forming gels with up to 99.5% water and remaining solid up to about 85°C . Agar has a major use in microbiological media as it is not easy for microorganisms to metabolize and forms clear, stable and firm gels, but in the food area it is used in icings, glazes, processed cheese, jelly sweets and marshmallows. It may be used in tropical countries and by vegetarians as a substitute for gelatin.

Interactive structures are available (COW Plug-in, ActiveX; Chime).

Please submit any comments and suggestions you may have.

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This page was last updated by Martin Chaplin
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